

Building A Gas Pipeline Through The Arctic

# What about the Permafrost?

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What Is Permafrost?

Permafrost is perennially frozen ground — that is, earth materials such as soil and rock that have remained continuously below 32°F (0°C) over at least one summer, regardless of whether they are actually frozen. In most cases, however, the ground has been frozen for many thousands of years. The term "permafrost" merely describes the thermal condition of the ground; it does not imply the absence of water, or its presence in either the solid or liquid state. In many cases permafrost ground contains large volumes of ice, or in some cases dissolved salts may cause free water to exist because its freezing point is lower than 32°F.

In Canada and the U.S.S.R., permafrost underlies about one-half of the land area; in comparison, only about twenty percent of the earth's total land surface is affected by permafrost.

Ground temperatures (measured at a depth where no seasonal variation occurs) often correlate with the mean annual air temperature of the region, with the mean annual ground temperature always being a few degrees warmer than the mean annual air temperature. This, however, is a generalization, since the temperature difference depends upon local climate and terrain factors such as soil type, water content, and geological structure.

Where Does Permafrost Occur Along The Pipeline Route?

Permafrost is distributed along the proposed gas pipeline route from Prudhoe Bay, Alaska and the Mackenzie Delta, Northwest Territories, to 50 miles south of Fort Vermilion, Alberta. The southern limit of permafrost in western Canada extends in a wide sweeping arc from near the Yukon-British Columbia border eastward to the southern tip of James Bay, corresponding roughly to the 30°F isotherm of mean annual air temperature.

Permafrost regions are divided into two zones that are distinguished on the arbitrary basis of ground temperature. (The terms "continuous" and "discontinuous" used to describe these zones should not be interpreted in their mathematical sense.) The continuous permafrost zone, which is the most northerly area, has a mean annual ground temperature of 23°F or lower. The discontinuous zone, which is located predominantly in the southern portion of the permafrost region, has a mean annual ground temperature between 23°F and 32°F. The boundary between these zones is located primarily between the 15°F and 20°F isotherms of mean annual air temperature, and crosses the pipeline route just south of Fort McPherson.

In the continuous zone, permafrost occurs nearly everywhere and its thickness varies from 200 feet at its southern limit to over 1800 feet in the most northerly part of Canada. In the discontinuous zone, permafrost is separated by unfrozen ground both vertically and horizontally. In the southern fringe of the discontinuous zone there are only scattered occurrences of permafrost, present mainly in peatlands, on north facing slopes, and in forested stream banks. Further north in this zone, the permafrost becomes increasingly widespread until it is more or less continuous.

In the continuous permafrost zone, evidence exists that the permafrost table does not extend below bodies of water that do not freeze to the bottom in winter. The Mackenzie River is an example, although some of the islands within the Mackenzie River still are permafrost affected. Lakes that are close to one another, and oxbows such as these occurring in the Mackenzie Delta, probably also bound isolated volumes of permafrost.

A third zone of permafrost is characterized by uncommon occurrences of permafrost. Sometimes referred to as the "sporadic permafrost zone", it extends southward from the discontinuous zone. These scattered occurrences are hazardous from an engineering viewpoint since they generally occur where they are not expected.

The "active layer" is the upper portion of surface materials that thaws each summer and refreezes each winter. Depending upon moisture conditions and seasonal temperatures, its thickness varies from year to year. Normally, however, in the continuous zone it extends to the permafrost table (the locus of subsurface points at which ground temperatures do not exceed 32°F over a period of one year or more).

In the discontinuous zone, the seasonal frost often does not penetrate to the permafrost table; that is, there is sometimes an unfrozen layer between the permafrost and the bottom of the soil layer that froze during the previous winter. In addition, the thickness of the active layer decreases from south to north. For example, at Fort Simpson it can vary in depth from 5 to 20 feet, reducing to 2 to 4 feet at Norman Wells and even less at Inuvik.



This buried massive ice is being eroded by flowing water. The straight vertical bank implies the erosion process is uniform, but the tundra-covered ice in the stream indicates at least occasional piecemeal progression. Ground conditions above this ice mass offer no visible surface evidence of its presence.



Close-up view of the massive ice formation exposed in the bowl-shaped landslide shown on the back of this brochure. The ice measures 30 feet across at the top and is covered by a 2 or 3 foot thick mat of soil, peat and tundra plants. The extent of the crater and subsidence indicates that the slide has been enlarging for several years.



Melting of large ice formations following surface disturbance by fire has led to the development of this erosion trench near Inuvik. Note: the buried ice (circled).



## Why Are We Concerned About Permafrost?

Experience has shown that special design and construction techniques are required for structures on some kinds of permafrost. Our primary concern about permafrost relates to the melting of high-ice-content soils that will be initiated if construction activities disturb the surface vegetation. The melting caused by surface disturbance of high-ice-content soils leads to ground subsidence or erosion as the excess water is expelled. The surface disturbance not only results in terrain degradation, but also greatly reduces the strength of the substrate as a foundation material for structures.

In many areas to be traversed by the proposed pipeline, and particularly on the coastal plain, high-ice-content soils are common. Where the permafrost is ice-free, these problems are not as serious.

Since the natural vegetation and its organic debris in the form of peat insulates the permafrost, disturbance of the vegetative cover upsets the thermal equilibrium causing melting and lowering of the permafrost table (referred to as permafrost degradation). In some cases, disturbance may only cause an increase in the depth of the active layer, with consequent changes in the forces acting on structures penetrating the active layer or embedded in it. In more severe cases, degradation of the permafrost table may lead to general ground instability, subsidence, or differential movements large enough to cause serious damage to both the pipeline and the adjacent terrain.

Ice is not necessarily present in permafrost; but when present in excess, it is of particular significance because of the abundance of free water that is released upon its melting. High-ice-content permafrost that melts may lead to complete loss of support for a structure, or to slides of river banks and hillsides, which could result in a pipeline break. Alternatively, it could lead to gullying and ponding on the landscape. Surface impoundment of water decreases the albedo (reflective power) of the ground surface and increases light absorption. This elevates the water temperature and leads to progressive states of thaw, ponding and ground slumping.

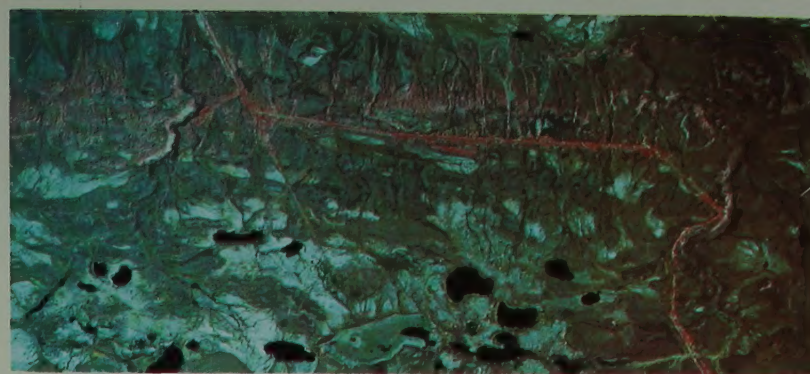
Sedimentation of rivers and streams due to mechanical erosion or thermal erosion (melting which provides material, and supplements the water supply as a transport mechanism) also is a major environmental concern.

The strength of permafrost is critically dependent upon the soil mass remaining frozen. In this respect the discontinuous zone of permafrost offers a greater hazard than the continuous zone, since its ground temperature can be precariously close to the melting point. The subcooled water that is often associated with permafrost also influences the thermal balance, and introduces the possibility of reduced strength. Hence, facilities that are to be built in the permafrost zone pose major problems to designers and constructors. The proposed pipeline and its appurtenances, such as compressor stations, must therefore be designed so that permafrost melt either will not occur or cause damage to structures due to settling or shifting of the foundation soils.



I. Reinart

This natural topography is technically known as thermokarst. It is characterized by "islands" of permafrost surrounded largely by unfrozen peat-filled depressions which at one time were icy sediments. New thermokarst topography possibly could form if the ground temperature is increased (i.e. brought on by disturbance of the vegetative cover during pipeline construction). Such thermokarst development could result in disruption of the normal supply of drainage water to certain wetlands.



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Increased emission of infrared radiation can be captured by photographic techniques to delineate areas of rejuvenated vegetation where the permafrost table has regressed due to disturbance. This infrared photograph shows the Canol Road close to where degradation of the permafrost table was recently measured for the illustration below.

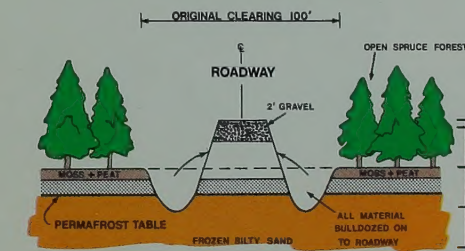
## Prediction of Permafrost Degradation

Although infrared techniques and visual observation by experienced personnel have developed sufficiently to detect permafrost degradation, these methods do not indicate the amount or rate of vertical regression, nor can they be used to predict the long-term stabilized position. If the areal limit of disturbance, soil properties, ice content and moisture condition are known for a particular location, both the depth of permafrost regression in time and the long-term equilibrium condition can be estimated by computerized mathematical techniques.

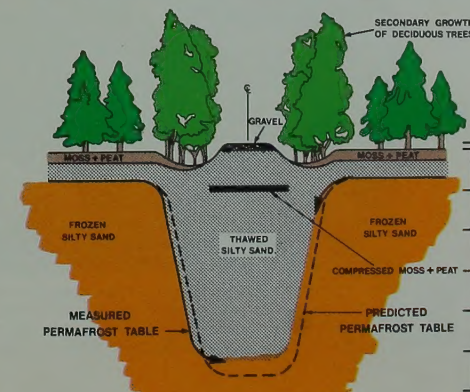
To test the reliability of such a method, the actual degradation that has taken place over a certain time interval must be measured and compared with predicted values for a disturbed area. Such a comparison has been made on certain portions of the Canol Road, which was constructed in 1942 to provide access for construction and maintenance of an oil pipeline from Norman Wells to Whitehorse in the Yukon Territory.

When the regression depth was measured in 1970, the permafrost table (represented by the solid line in the sketch) was established by borings; the predicted permafrost levels are those shown by the dashed line. Beneath the right-of-way the permafrost table was roughly trough-shaped and about 18 feet deep. In the uncleared areas adjacent to the right-of-way, the permafrost table was 2 to 3 feet below the original ground.

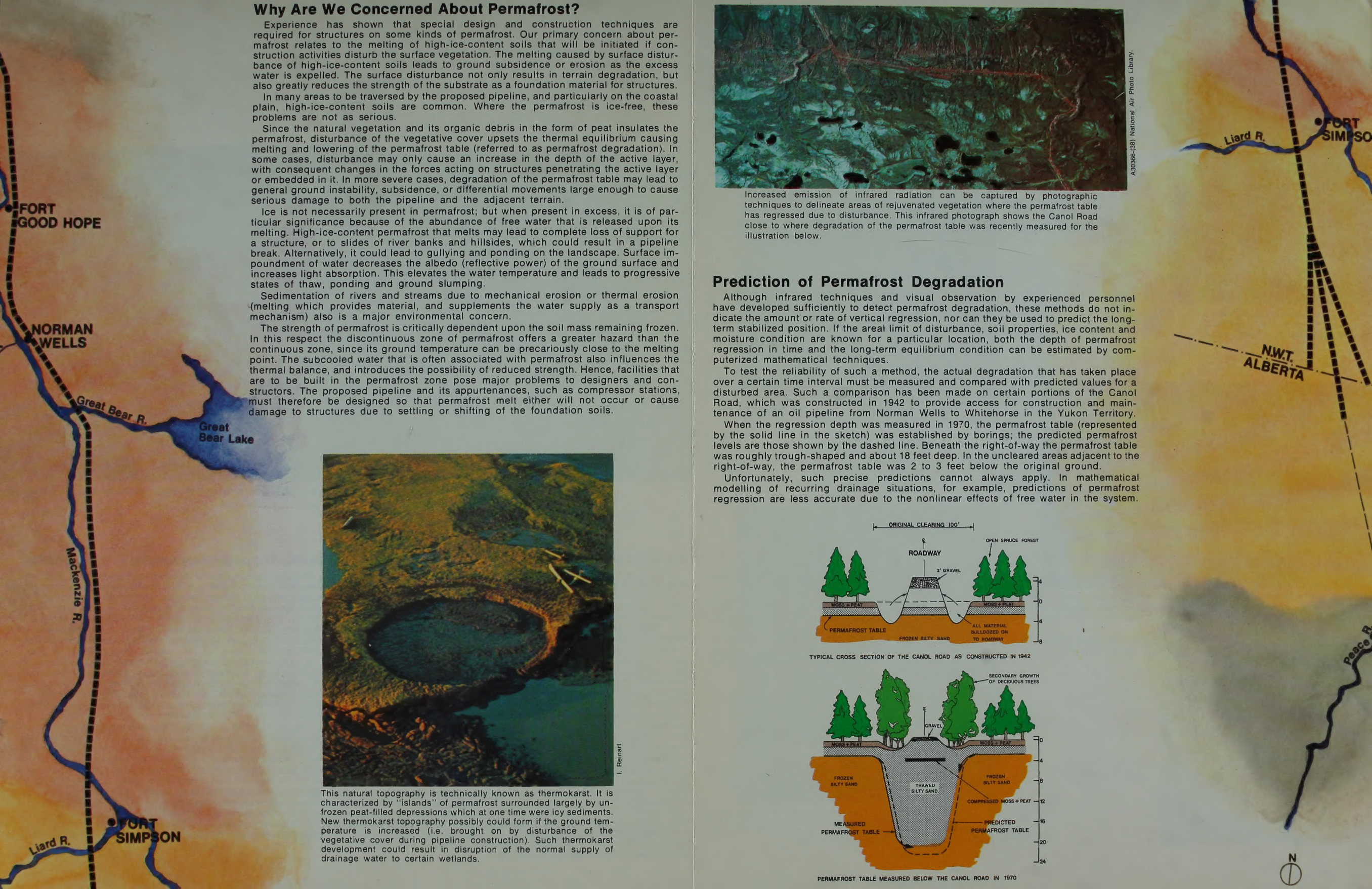
Unfortunately, such precise predictions cannot always apply. In mathematical modelling of recurring drainage situations, for example, predictions of permafrost regression are less accurate due to the nonlinear effects of free water in the system.



TYPICAL CROSS SECTION OF THE CANOL ROAD AS CONSTRUCTED IN 1942



PERMAFROST TABLE MEASURED BELOW THE CANOL ROAD IN 1970





# Environment Protection Board

In 1970 the Environment Protection Board began studying effects on the natural environment of construction and operation of a natural gas pipeline through the Yukon and Northwest Territories. The study involves collecting baseline data, incorporating environmental planning into pipeline design, assessing impact, preparing guidelines for education and control of construction personnel and evaluating post-construction activities. The Board, now sponsored by Canadian Arctic Gas Study Limited, is composed of specialists in Arctic research or environmental science.

The Board, an autonomous body, is guided by the following objectives:

- 1) To become sufficiently familiar with arctic ecosystems in the area of pipeline operation to permit estimates of biological costs or benefits of construction and judgments about the potential for widespread damage or major disruption of ecosystems.
- 2) To become sufficiently familiar with biological and physical environments so that pre-construction findings can be used as a basis for post-construction evaluation.
- 3) To make recommendations and conduct briefings so that results of the Board's deliberations can be used for maximum environmental protection.
- 4) To make available results of its studies as a direct contribution toward northern scientific development.

The Board's deliberations are to continue throughout the life of the proposed four-year construction project and for a suitable period during the operational phase.

Members of the Environment Protection Board are: Mr. C.H. Templeton (Chairman), Dr. L.C. Bliss, Dr. M.E. Britton, Mr. D.W. Craik, Mr. E. Gourdeau, Dr. I. McTaggart-Cowan, Dr. S. Thomson, Dr. N.J. Wilimovsky and Mr. R.C. Isaak (Secretary).

Outside specialists are used for specific assignments. Administrative support for the Board is supplied by Interdisciplinary Systems Ltd., 528 St. James Street, Winnipeg, Manitoba.

*Additional copies of this brochure  
may be obtained from:*

**ENVIRONMENT PROTECTION BOARD**  
528 St. James Street  
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Ground Ice Description

The ice in permafrost may have many forms. It may not be discernible to the unaided eye, but it can act as a cementing agent in bonding together the mineral or organic materials, thus giving the frozen soil mass added strength. The presence of such ice may be revealed by crystal reflections, by a sheen on fractured surfaces, or by water release when the material thaws. Ice in fine-grained soil, upon melting, may form a slurry that has negligible strength resulting in flow or instability problems.

Ice in permafrost may also exist as individual ice crystals, as ice coatings on particles, or as random or distinctly oriented ice veins. Larger ice masses may exist as random or irregularly oriented layers, as vertical, wedge-shaped veins, or as large blocks and sheets sometimes many feet thick and hundreds of square feet in area.

The photograph (opposite centre) shows a drill core from permafrost which had an upper layer of frozen material containing nonvisible ice, and a lower section of segregated ice. In general, the amount and extent of ice increases from south to north in the permafrost region. But locating and delineating the extent of segregated ground ice is a difficult task. There is no doubt that some ice formations would remain undiscovered until exposed by trenching machines during construction of the pipeline, at which time remedial construction methods might be difficult.

To date, investigational techniques have not developed to a state that allows precise prediction of the existence, areal extent, or thickness of ice. For example, although a test hole drilled at a given location in the permafrost may clearly show the thickness and types of ice that the drill has penetrated, this finding cannot be used reliably to predict the extent of ice in terrain even a few feet away. Similarly, ice may be observed in exposures such as the face of slides or cuts, or it may be inferred to be present in areas of patterned ground such as that developed by the ice-wedge polygons (shown on the front cover of this brochure), but in neither case can its extent usually be predicted.

A knowledge of the geological origin of surface deposits, combined with a study of air photos and correlation of this information with available drill hole records and plant communities, can provide some idea of the permafrost areas most likely to contain ground ice in quantity. The designer can then take appropriate measures (such as cooling the gas to a temperature below 32°F) to minimize thermal disruption in critical areas of the route. Field reconnaissance and extensive test hole drilling may also be necessary in some critical areas.

Pingos

Ice wedge polygons, palsas and pingos are landscape features caused by accumulation of ice. The pingo (an Eskimo word meaning "the conical one") is a unique feature of the Arctic, which in contrast to other ground ice features is elevated high above the surrounding terrain. Pingo hillocks exist up to 150 feet high and consist primarily of ice. They are readily recognized and thus can be easily avoided during northern development. Presently known pingos in Canada number well over a thousand, and virtually all occur northeast of the Mackenzie Delta.

Pingos originate from arching of an impervious sheet of permafrost forced up by water under pressure. They can be of two types, depending upon the mechanism of their formation. The open type is fed by an external water supply, whereas the closed type derives its water supply internally (resulting from the expulsion of excess pore water upon freezing of a confined body of saturated or supersaturated soil). Most pingos are associated with old lake beds which consist of thick deposits of sand of alluvial, deltaic or glaciofluvial origin. However, the open type pingo generally occurs close to slopes where water under pressure is more common.

Palsas are elevated peat mounds occurring more along the southern fringe of the discontinuous zone. The formation of palsas is associated with the same mechanism as that for a closed type pingo, although on a much smaller scale.

One of two major pingos near Tuktoyaktuk, N.W.T. that are well over one hundred feet high. The surrounding low lake bottom terrain is typical of the locale of these ice-cored hillocks.



A classic mudslide (circled) on the edge of the arctic coastal plateau just west of the Mackenzie Delta. Bowl-shaped slides like this exist throughout the terrain to be traversed by the proposed pipeline, most being induced by natural causes.



Vertical drill core taken from the continuous permafrost zone. Note frozen material containing nonvisible ice in upper section (left) and clear ice at lower level (right).



This close-up view shows active thermal erosion involving the movement of many cubic yards of earth, most of which has been transported down the face of the scarp. This action will progress until the exposed ice is insulated by natural debris from the tundra mat, or by material too large for transport. Natural or man-made disturbances such as these can be impeded by replacing the insulative layer with fill material.



Ice wedge cross-section exposed in a bowl-shaped slide. The troughs which delineate the ice wedge polygons shown on the cover of this brochure are generally underlain by ice wedges three to six feet wide at the top. The white material in the foreground is a massive body of ice.





Panoramic view of the same bowl-shaped slide shown in the aerial view to the left. This slide measures approximately 100 feet across and the depth of its vertical backface varies between 12 and 18 feet. The thawing is thought to have begun in 1968 or 1969.

I. Reind

## Ice Wedge Formation

The origin of ice wedges is generally accepted to be the result of thermal contraction in the frozen tundra, which during the arctic winter forms vertical tension cracks approximately one-tenth of an inch wide and several feet deep; often they form a polygonal pattern. In the early spring, hoarfrost and meltwater from the snow gravitates into these cracks and produces a vertical vein of ice which penetrates the permafrost.

After the cracks have established and become refilled, thermal expansion of the formation during the summer results in elevation of the centre of the polygon, possibly through plastic deformation of the material bounded by the planes of weakness. Cyclic seasonal expansion and contraction, repeated over centuries, eventually produces the large wedge-shaped masses of ice along these planes.

The polygonal pattern is thought to be a natural consequence of contraction (as in a drying mud flat). Although ice wedges are always present where the surface polygonal pattern is evident, the reverse cannot be assumed: absence of the polygonal feature does not assure the absence of ice wedges beneath the ground surface.

The existence of ice wedges, particularly along those portions of the proposed pipeline route in the continuous permafrost zone, pose a major problem for the pipeline designer. Thawing of the wedges will create planes of weakness that may result in increased slide activity on sloping ground and reduced support for the pipe. Even greater problems may be caused by the cyclic contraction and expansion stresses on pipe sections that pass through and bear on active ice wedges. In addition, increased drainage and siltation would result from melting ice wedges.

## Bowl-Shaped Depression

One of the many remarkable surface phenomena resulting from high-ice-content formations, the bowl-shaped depression is readily recognized from the air; its effects are most pronounced, however, when viewed from the ground. Because of its high water content, the thawed soil is exceedingly mobile and even on the slightest incline tends to flow downhill. The bottom surface becomes very soft and wet, principally due to the melting of the segregated ice that has been exposed.

A particularly interesting aspect of such depressions is that the large amounts of segregated ice beneath the surface cover may not be reflected in or evident from the type of terrain in the area (i.e. there may be no patterns or cracking). This was the case for the situation shown above, where some of the ice was located immediately under the tundra mat.

The implications of such slides are great. Should this type of failure occur in the immediate vicinity of an installed pipeline, it is possible that the pipe could not withstand the forces exerted on it, and a break might ensue. From the environmental point of view, the mud flowing from such a slide could dam a watercourse or silt-up spawning beds of fish and destroy other aquatic life.

Although the natural cause of such slides is not clear, in each case it is related to the melting of large ice masses. It is significant, however, that these bowl-shaped failures are found as far south as Fort Simpson, indicating that massive ice exists at these more southerly latitudes even though drill coring has not encountered it.

## Methods to Reduce Impact

It is generally recognized that building a gas pipeline through permafrost terrain cannot be accomplished without some damage to or impact on the northern environment. There are, however, means and ways of reducing the impact of construction. Avoidance of high-ice-content areas and cross-slopes can eliminate a host of problems. Where this is not possible, special construction techniques and care can be exercised to ensure the least possible disturbance of the environment and to guarantee the security of the pipeline.

Many of the degrading ground ice features common in the permafrost regions to be traversed by the proposed pipeline are the results of a natural geologic or climatic course of events. But it is the careless activities of man which can easily initiate additional unstable features that will be undesirable from both engineering and environmental viewpoints.

Two special techniques are of particular significance to this project: (1) winter construction will be a requirement in many areas of the permafrost region, since summer construction disturbance would prove intolerable (except possibly in the Brooks Range); and (2) the gas could be chilled along the route to maintain the ground temperature at 32°F or lower in the vicinity of the pipe. Whereas winter construction will be a positive method to reduce impact, chilling of the gas might aggrade the permafrost table over the pipe so that interference of subsurface flows may result. The mechanism and incidence of ice build-up in the vicinity of a cold pipeline may also prove significant, although test facilities at four locations have not experienced this problem.

Often the design of roads, airstrips, and compressor station granular pads in permafrost regions entails determining the minimum thickness of granular fill to maintain the subgrade in a frozen state. This engineering solution to permafrost problems induces the permafrost table to rise above its normal levels. Fills are placed directly on the ground surface, usually by end dumping, with minimum disturbance to the ground surface. After a new thermal equilibrium is established, the permafrost extends into the non-frost-susceptible fill. The advantage of this aftereffect is the added strength of the substrate in its perennially frozen condition.

Pre-construction activities to reduce impact would include the thorough education of all peoples associated with the construction operation and, later, those responsible for operation and maintenance of the line. Post-construction precautions include replacement of the vegetation mat or mulch, and revegetation of the right-of-way.

The effectiveness of practically every method cited to avoid detrimental impact upon the environment depends on the same principle: that is, a complete understanding of and respect for the northern environment by every individual involved either directly or indirectly in northern development.